Supporting Information

Wauchope HS, Shaw JD, Varpe Ø, Lappo EG, Boertmann D, Lanctot RB, Fuller RA (2016) Rapid climate-driven loss of breeding habitat for Arctic migratory birds. *Global Change Biology*

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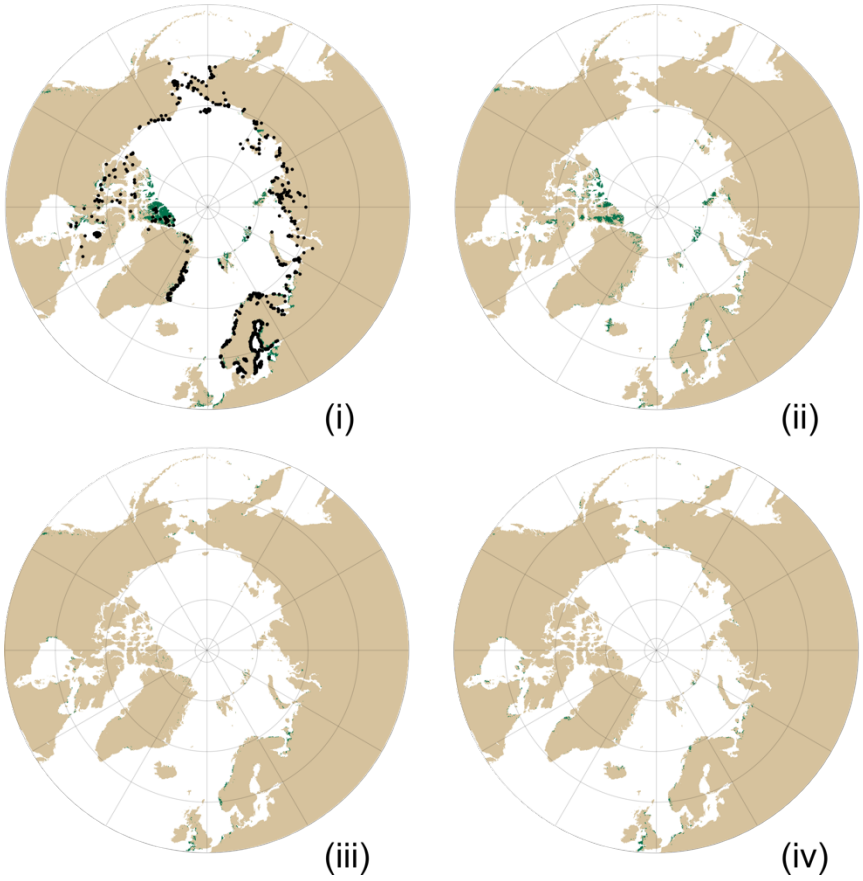
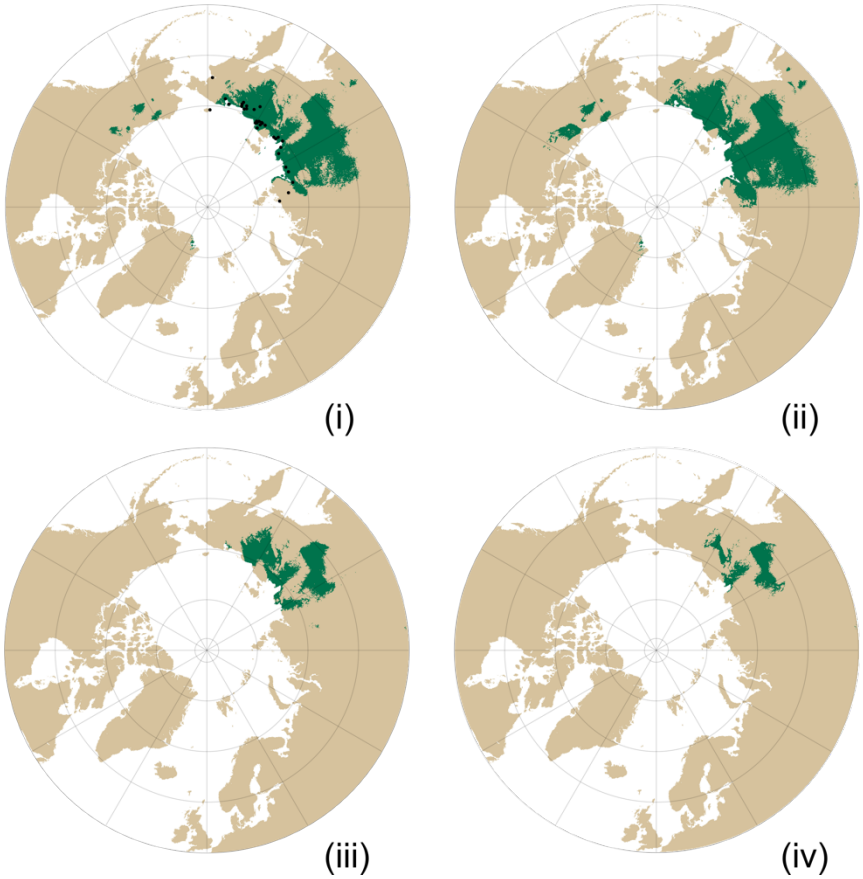
Table S1 - List of study species

Species Name	Common Name	Number of Occurrence Points
Arenaria interpres	Ruddy turnstone	1718
Calidris acuminata	Sharp-tailed sandpiper	34
Calidris alba	Sanderling	234
Calidris bairdii	Baird's sandpiper	398
Calidris canutus	Red knot	296
Calidris ferruginea	Curlew sandpiper	167
Calidris fuscicollis	White-rumped sandpiper	379
Calidris himantopus	Stilt sandpiper	135
Calidris maritima	Purple sandpiper	484
Calidris mauri	Western sandpiper	148
Calidris melanotos	Pectoral sandpiper	429
Calidris minuta	Little stint	306
Calidris ptilocnemis	Rock sandpiper	92
Calidris pusilla	Semipalmated sandpiper	601
Calidris pygmaea	Spoon-billed sandpiper	31
Calidris ruficollis	Red-necked stint	142
Calidris subruficollis	Buff-breasted sandpiper	196
Limnodromus scolopaceus	Long-billed dowitcher	102
Limosa haemastica	Hudsonian godwit	15
Numenius tahitiensis	Bristle-thighed curlew	759
Phalaropus fulicarius	Red phalarope	809
Pluvialis dominica	American golden-plover	298
Pluvialis fulva	Pacific golden-plover	646
Pluvialis squatarola	Grey plover	45

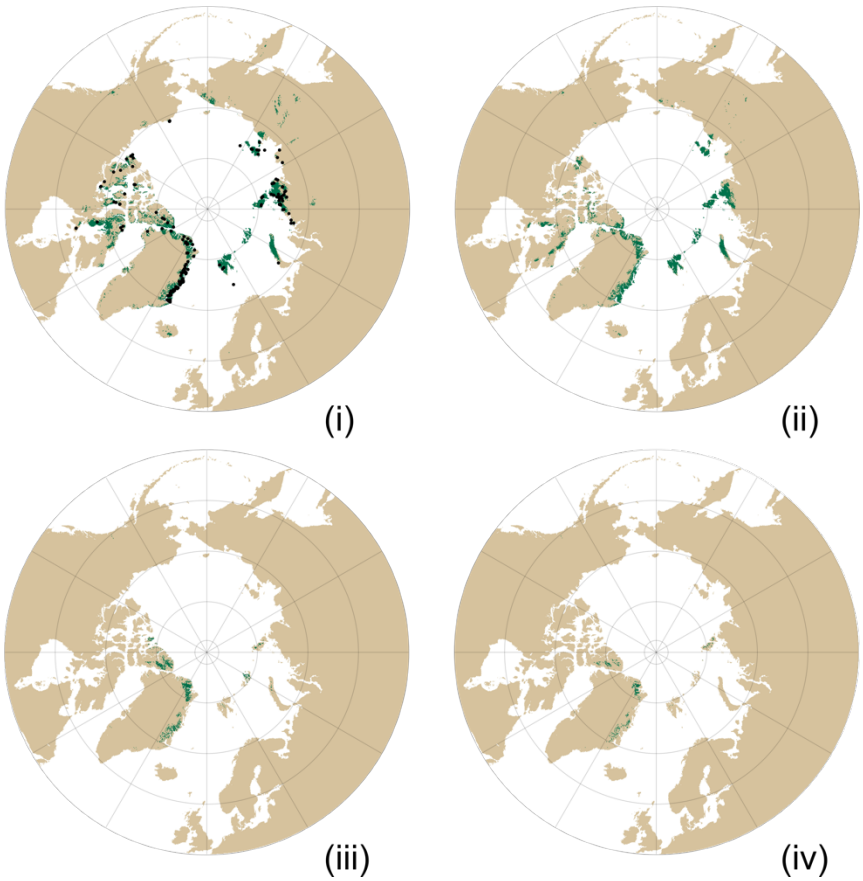
Figure S1 - List of individual species maps. Maps depicting where climatic habitat conditions are similar to where species are currently known to exist based on MaxEnt model projections of 24 Arctic-breeding shorebirds under current climatic conditions (i), climatic conditions at the Mid-Holocene climatic optimum (~6000 years bp, ii) and projected climatic conditions for 2070 under RCP 4.5 (iii) and RCP 8.5 (iv). The black dots on current maps (i) show locations of occurrence points used to create models.



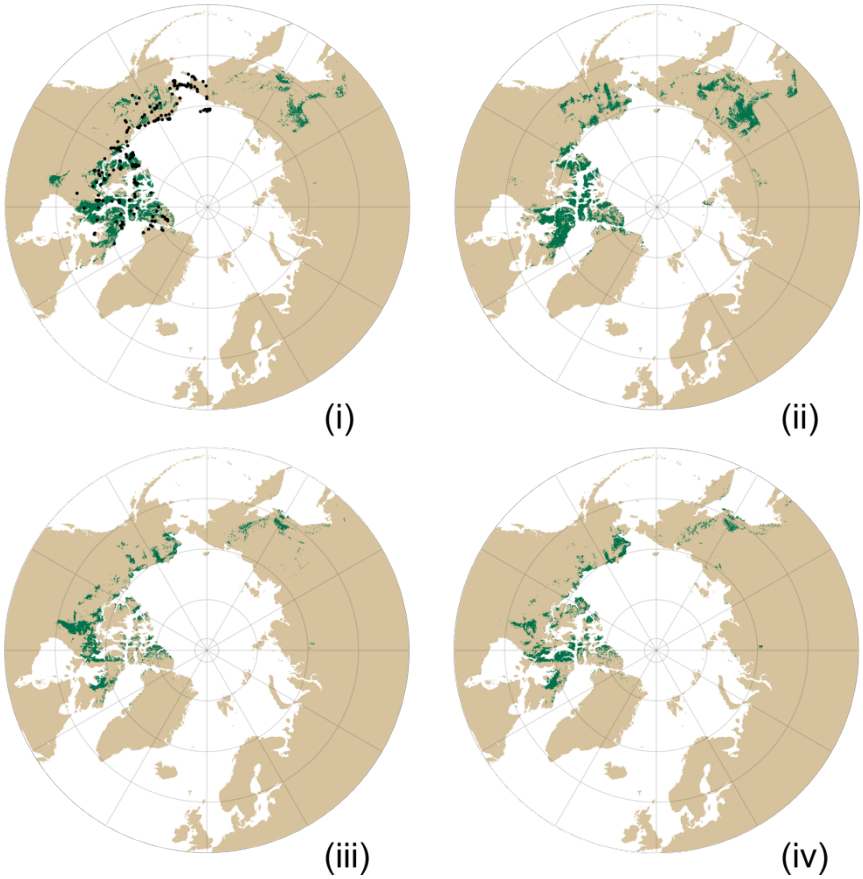
(a). Ruddy turnstone *Arenaria interpres*



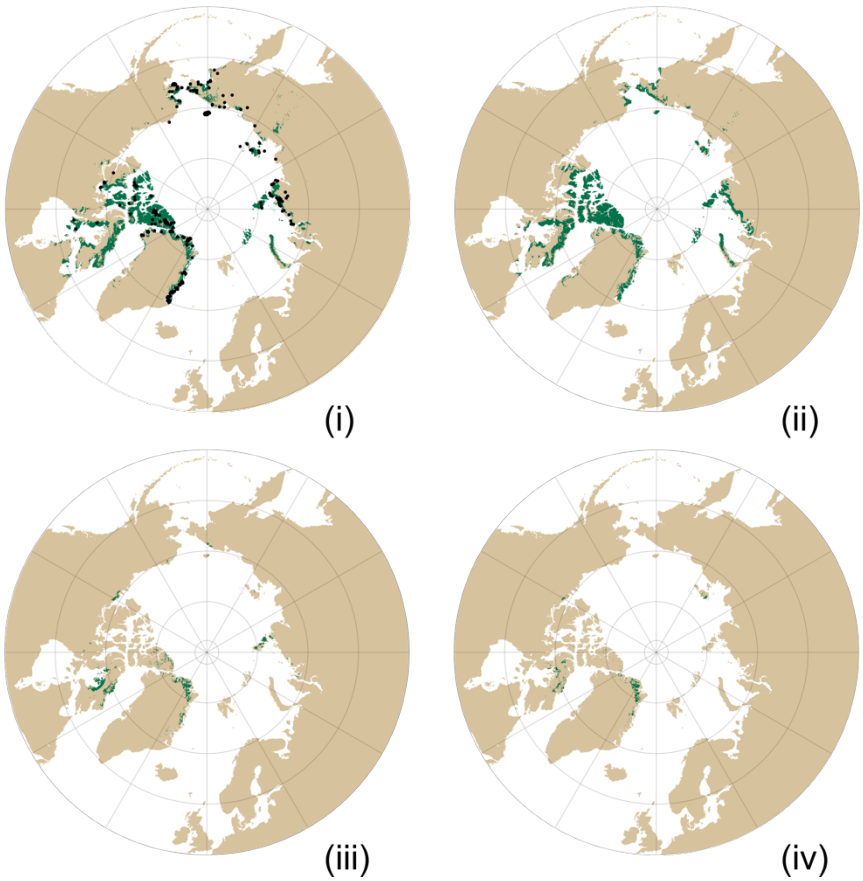
(b). Sharp-tailed sandpiper *Calidris acuminata*



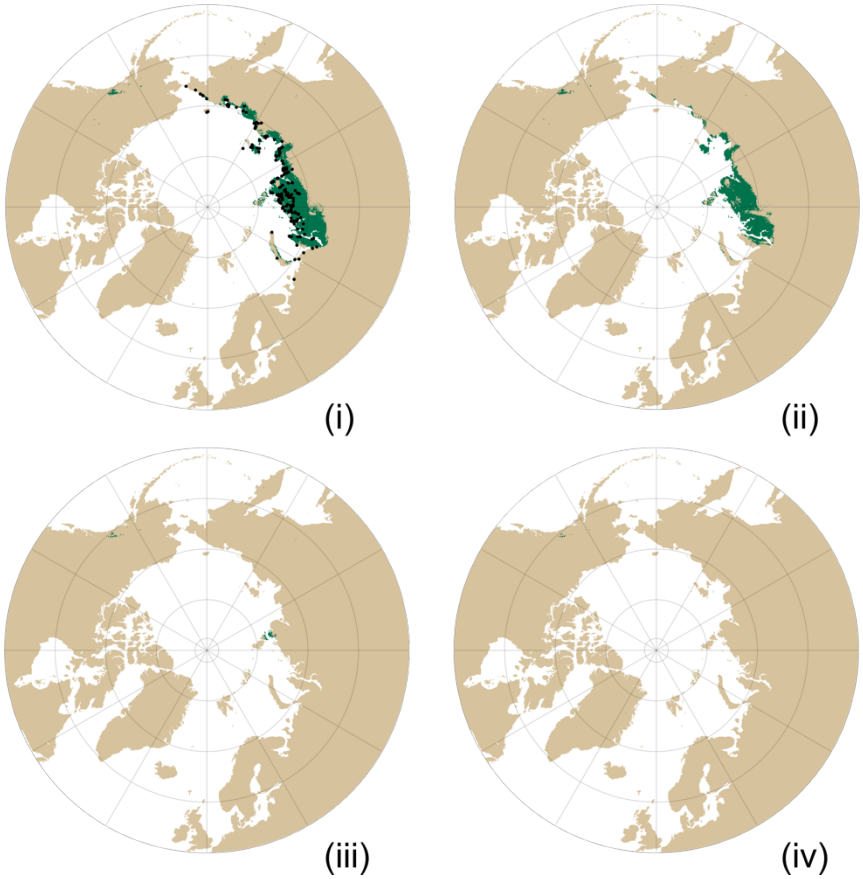
(c). Sanderling *Calidris alba*



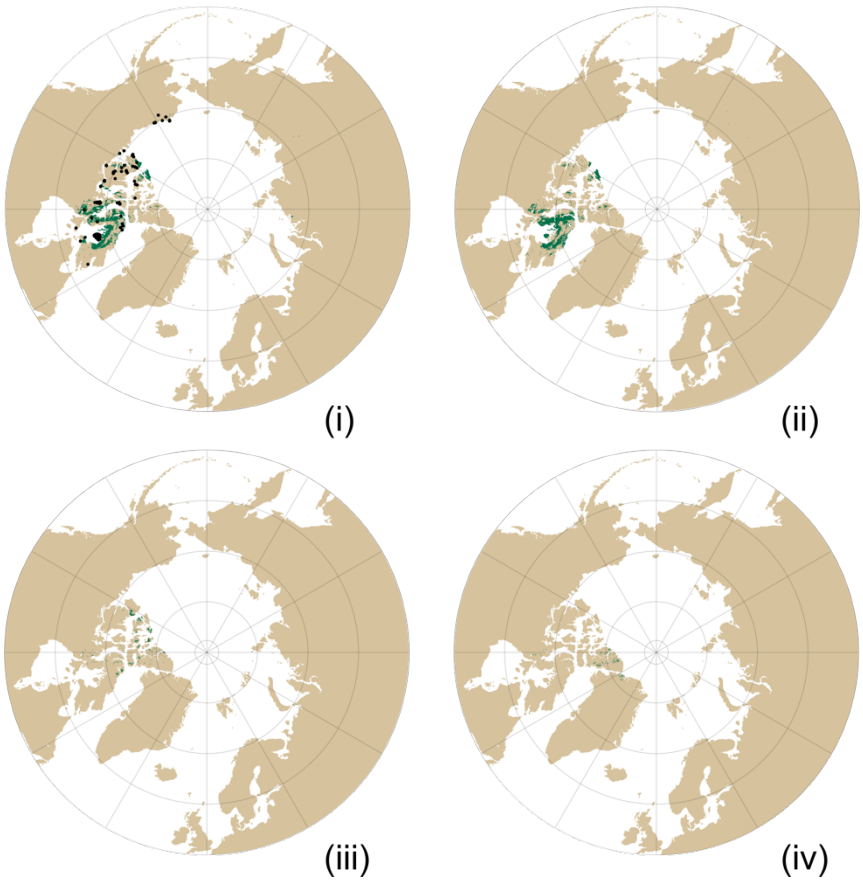
(d). Baird's sandpiper *Calidris bairdii*



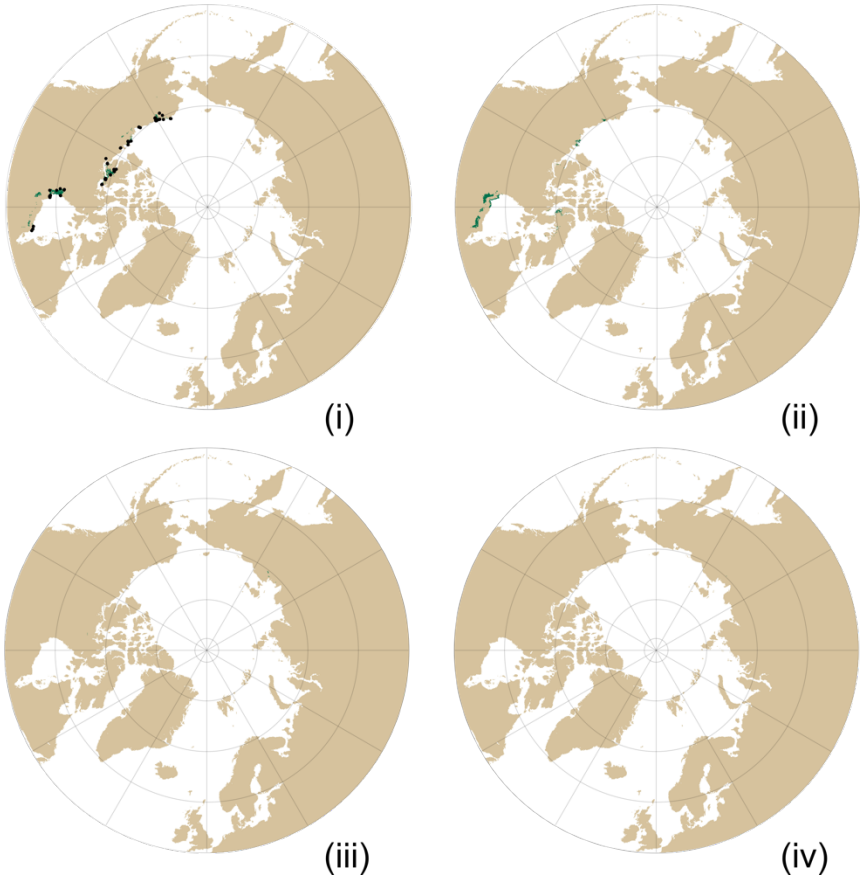
(e). Red knot *Calidris canutus*



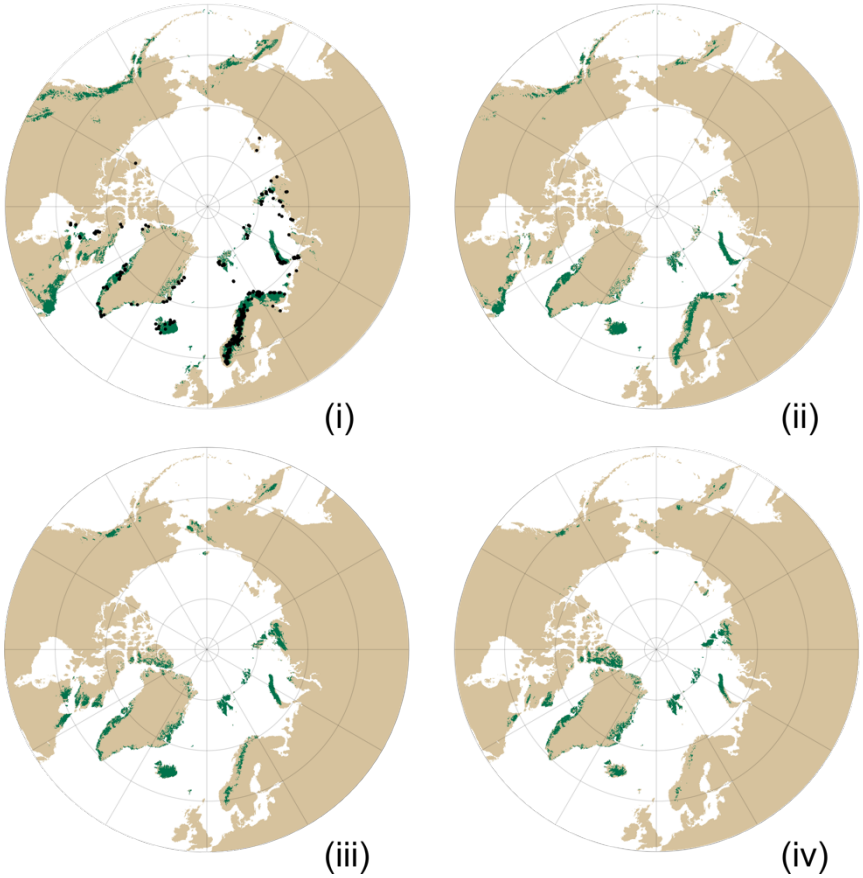
(f). Curlew sandpiper *Calidris ferruginea*



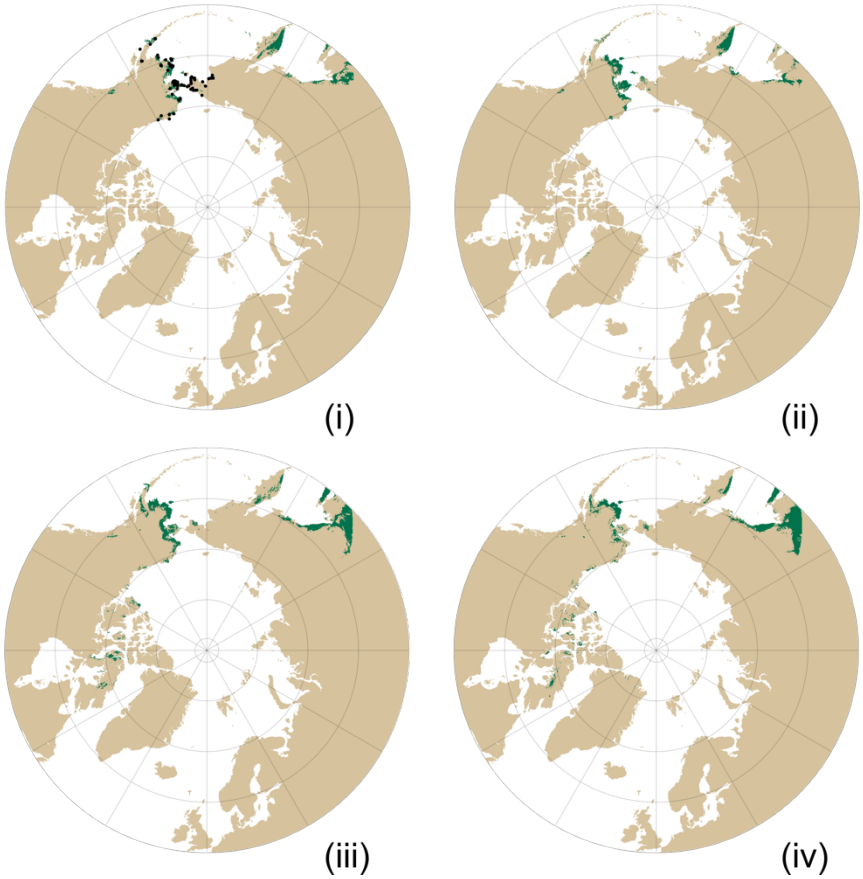
(g). White-rumped sandpiper *Calidris fuscicollis*



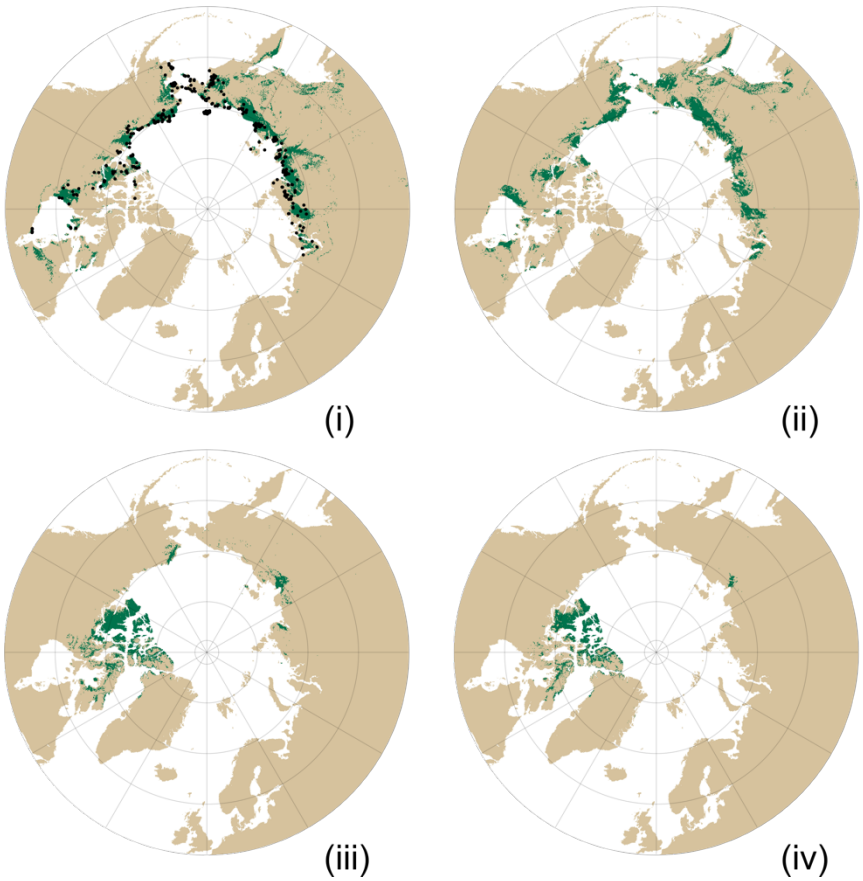
(h). Stilt sandpiper *Calidris himantopus*



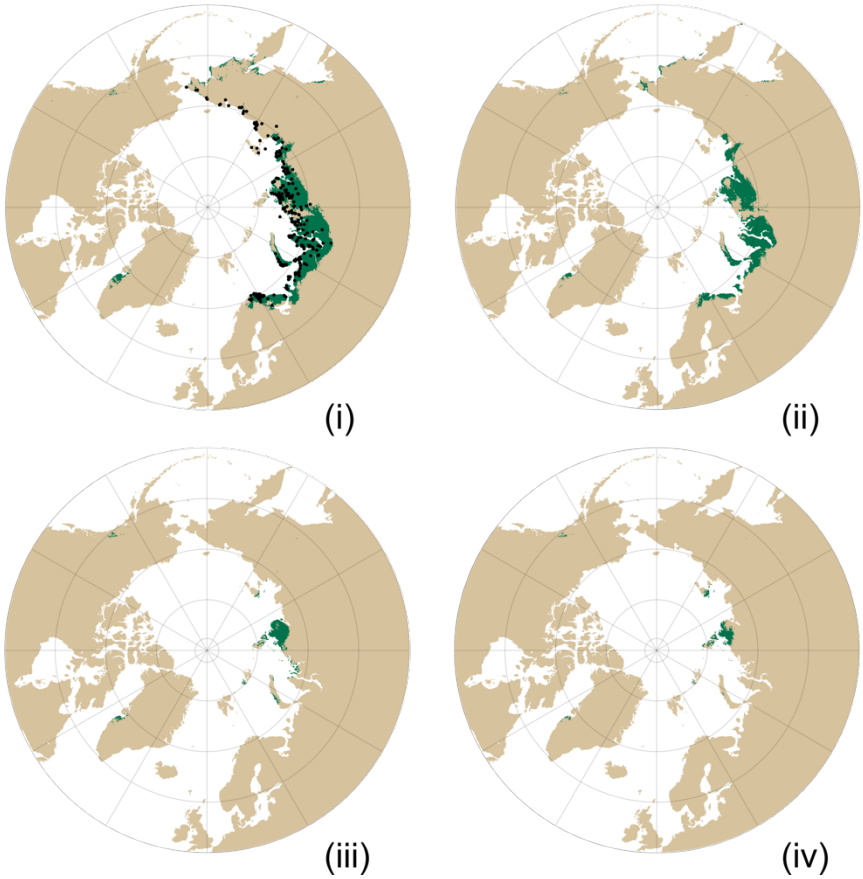
(i). Purple sandpiper *Calidris maritima*



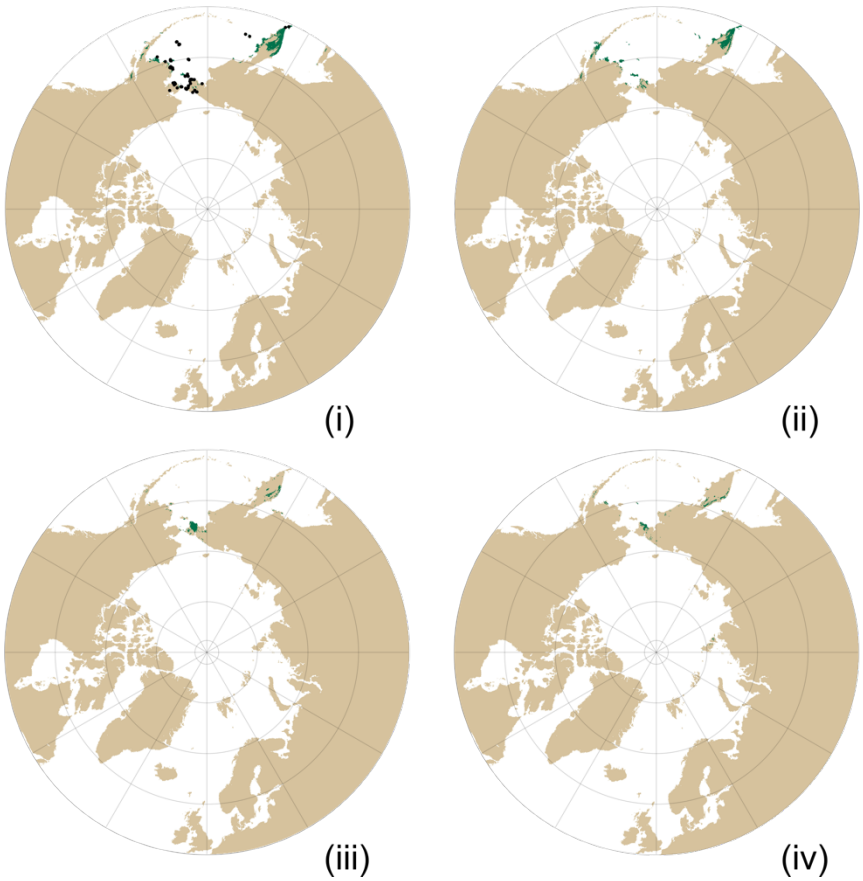
(j). Western sandpiper *Calidris mauri*



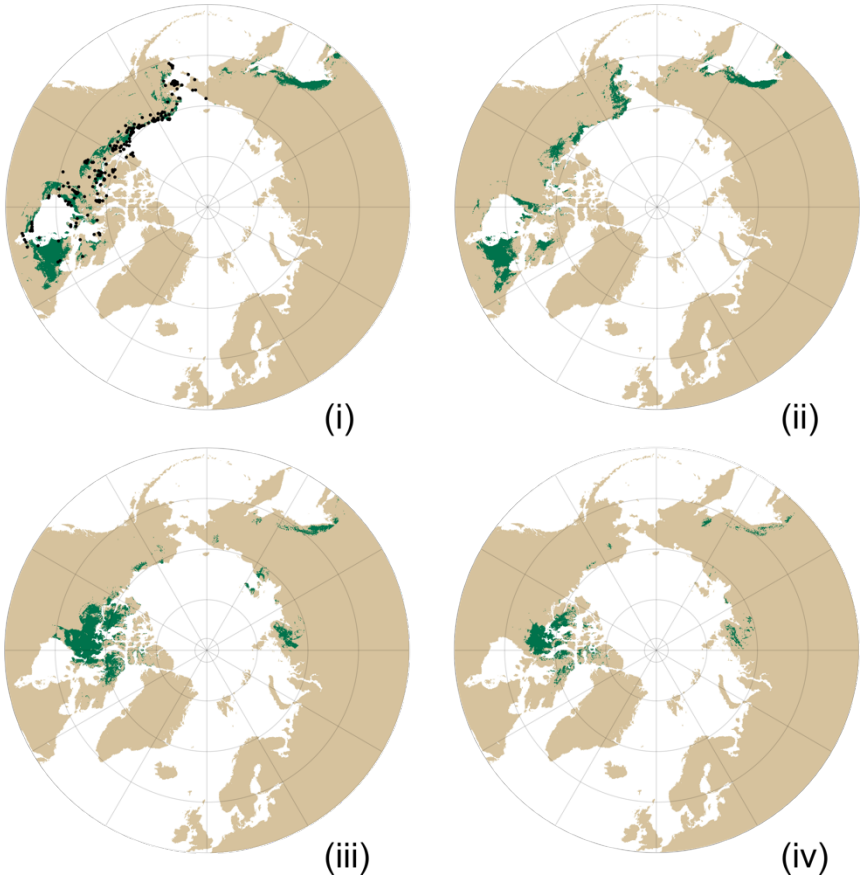
(k). Pectoral sandpiper *Calidris melanotos*



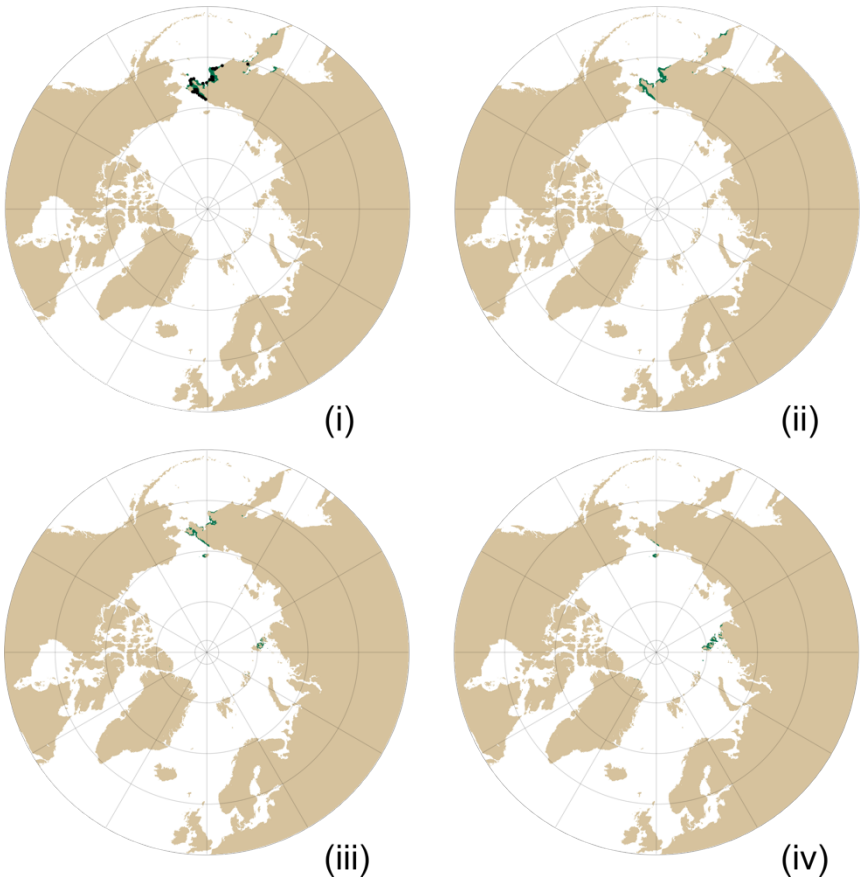
(l). Little stint *Calidris minuta*



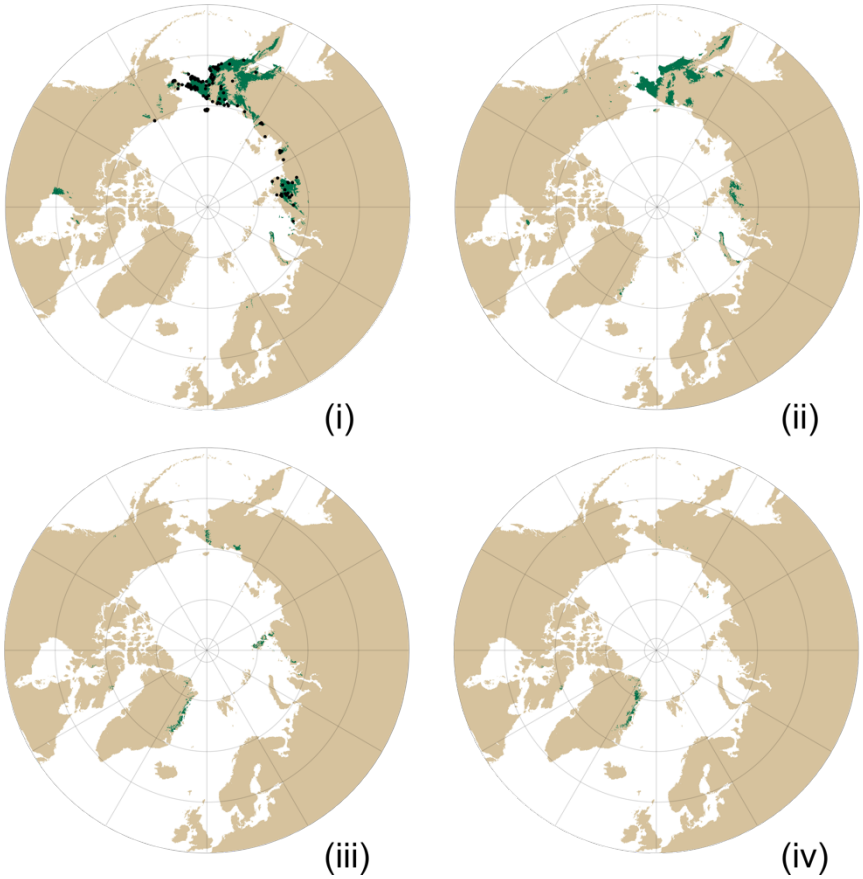
(m). Rock sandpiper *Calidris ptilocnemis*



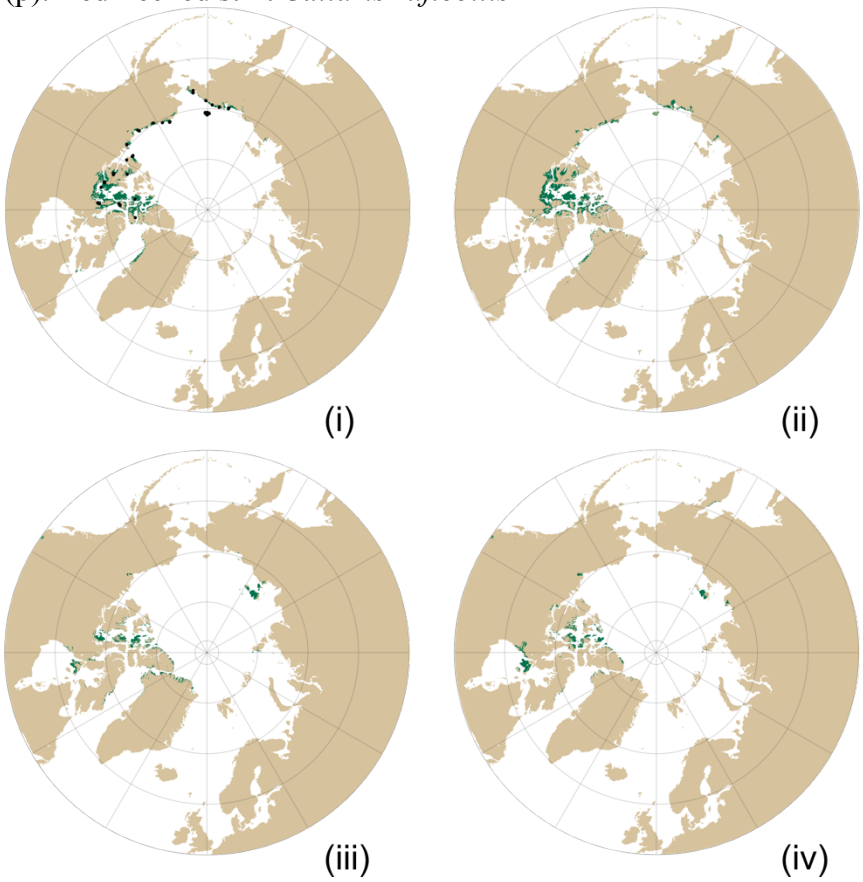
(n). Semipalmated sandpiper *Calidris pusilla*



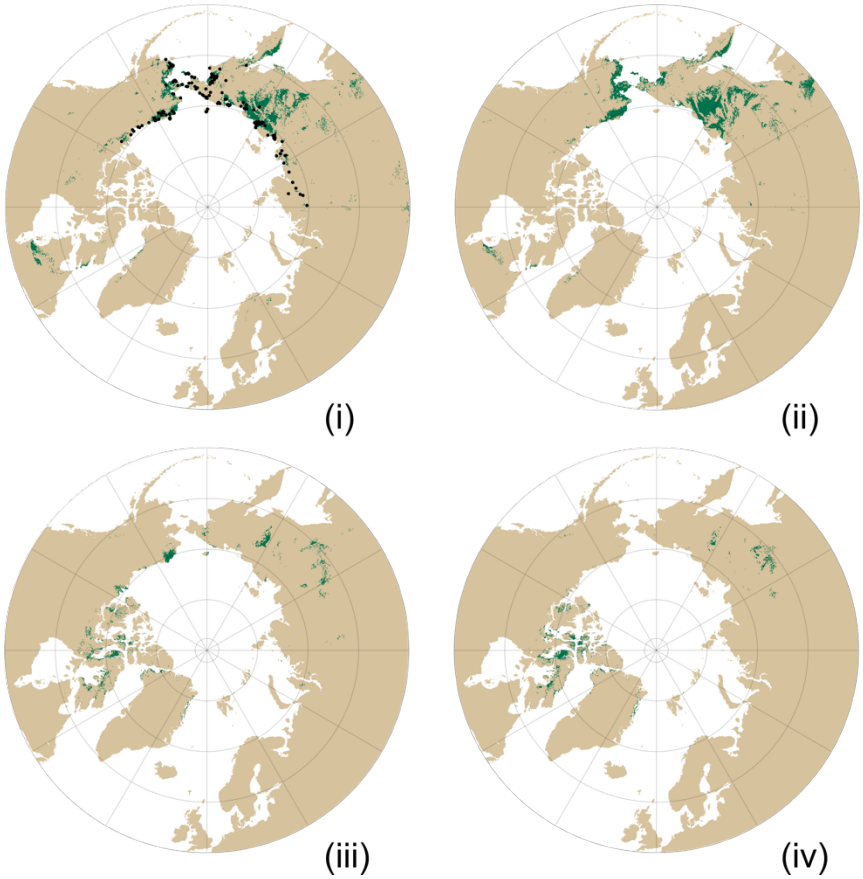
(o). Spoon-billed sandpiper *Calidris pygmaea*



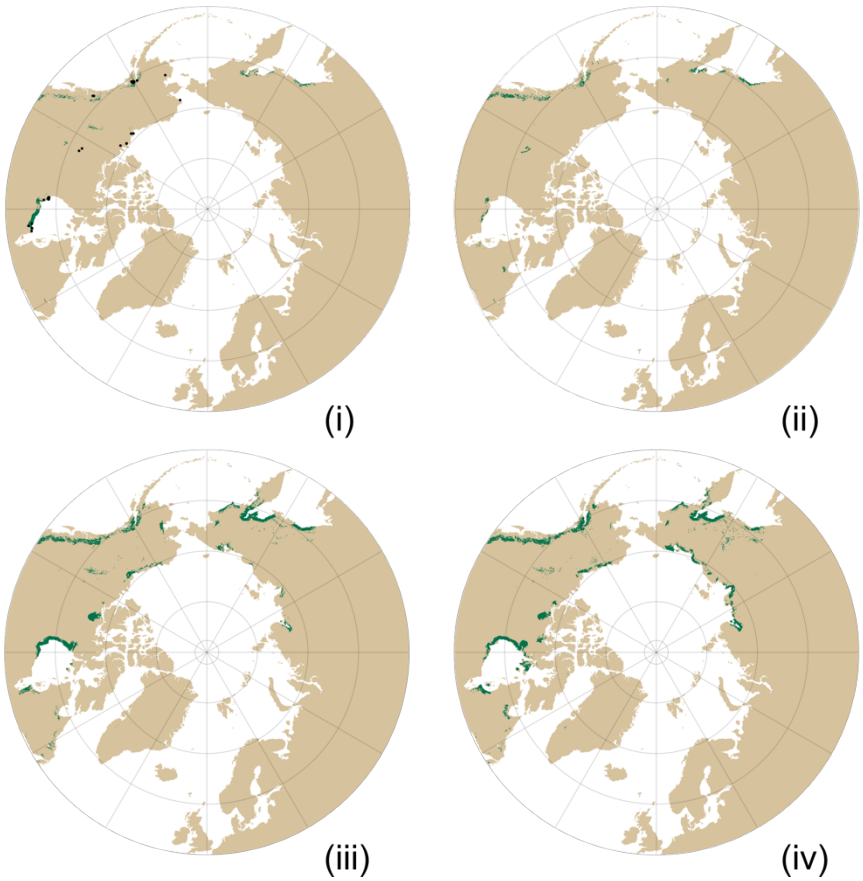
(p). Red-necked stint *Calidris ruficollis*



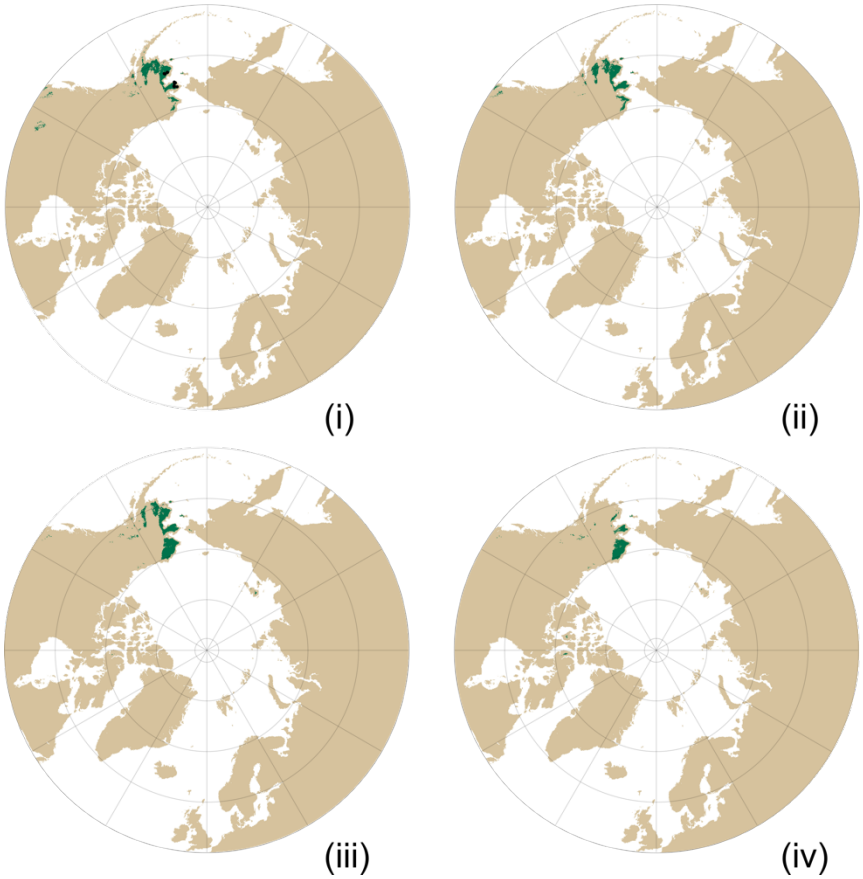
(q). Buff-breasted sandpiper *Calidris subruficollis*



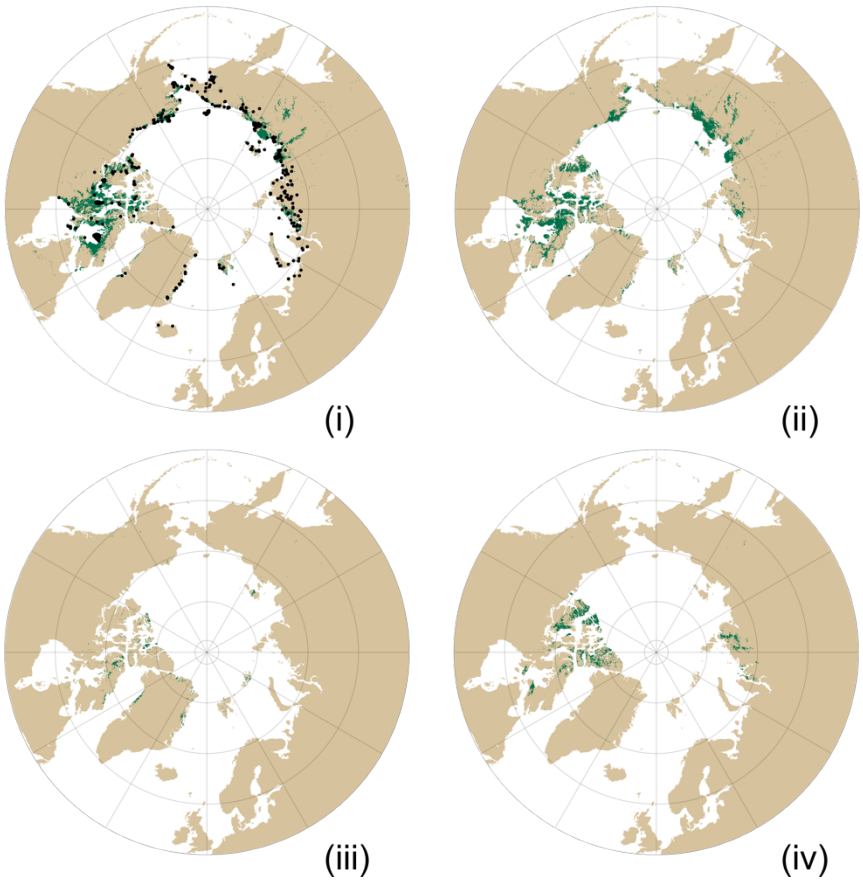
(r). Long-billed dowitcher *Limnodromus scolopaceus*



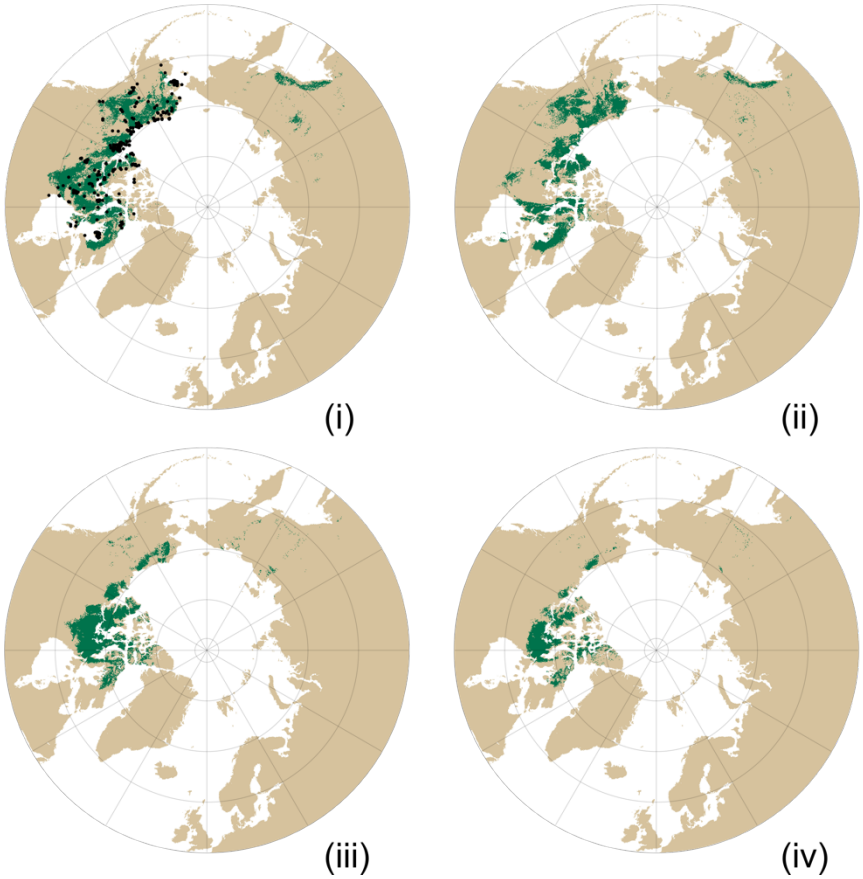
(s). Hudsonian godwit *Limosa haemastica*



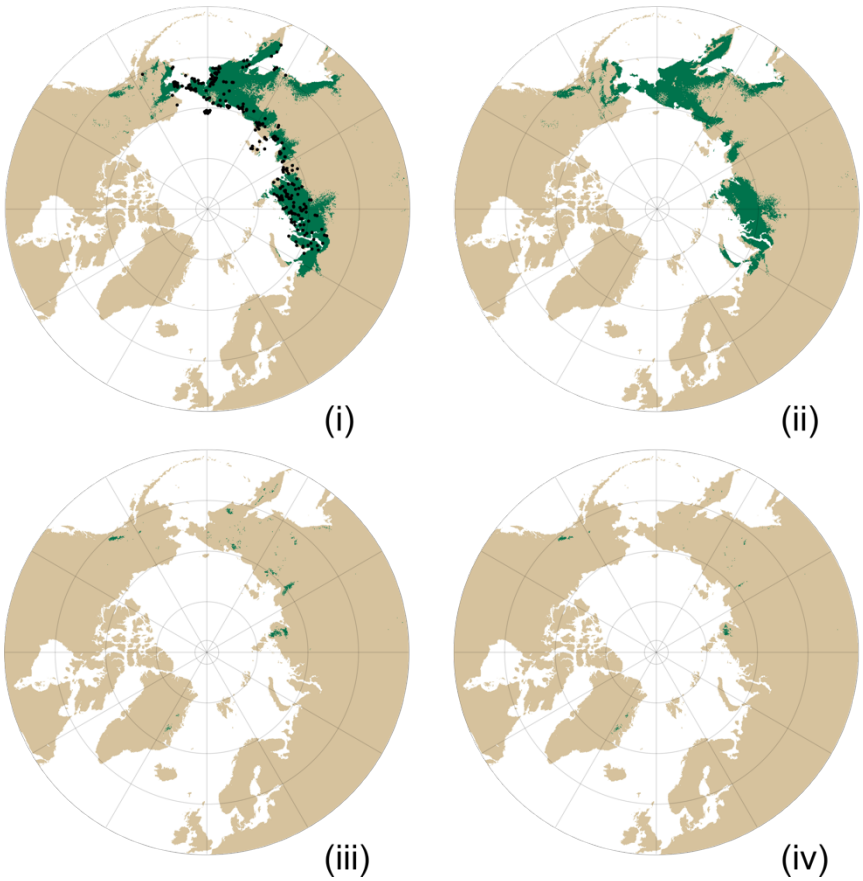
(t). Bristle-thighed curlew *Numenius tahitiensis*



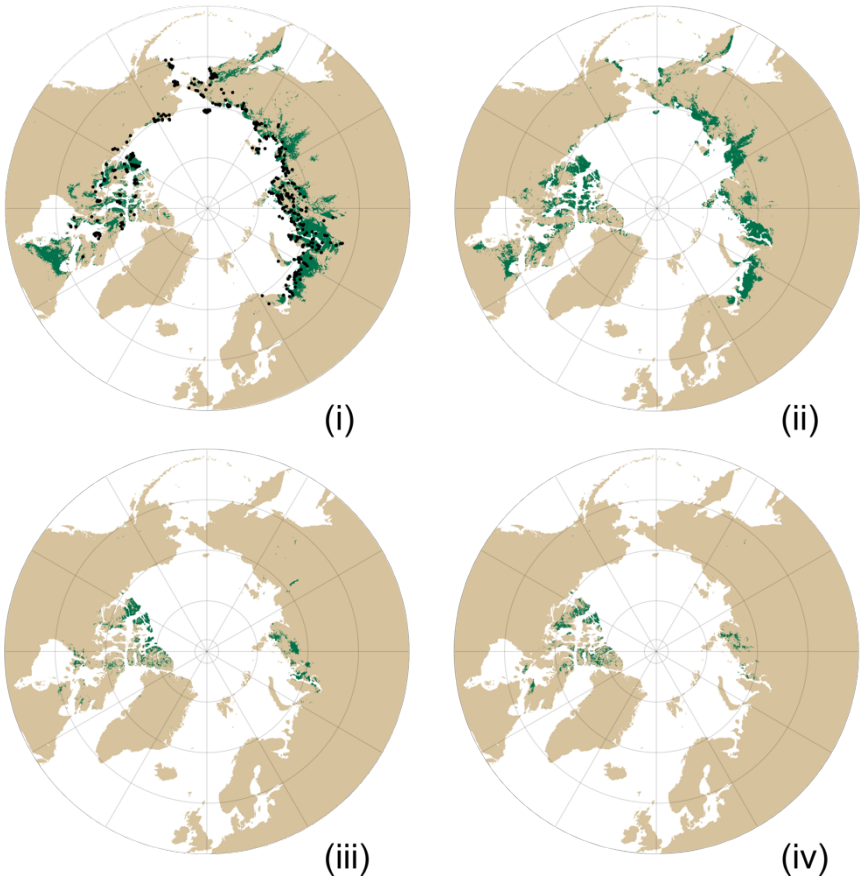
(u). Red phalarope *Phalaropus fulicarius*



(v). American golden plover *Pluvialis dominica*



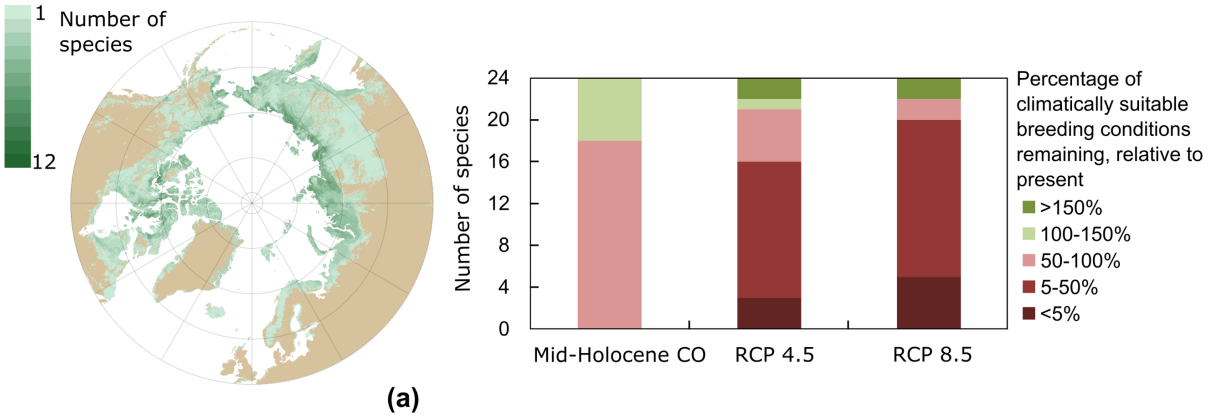
(w). Pacific golden plover *Pluvialis fulva*



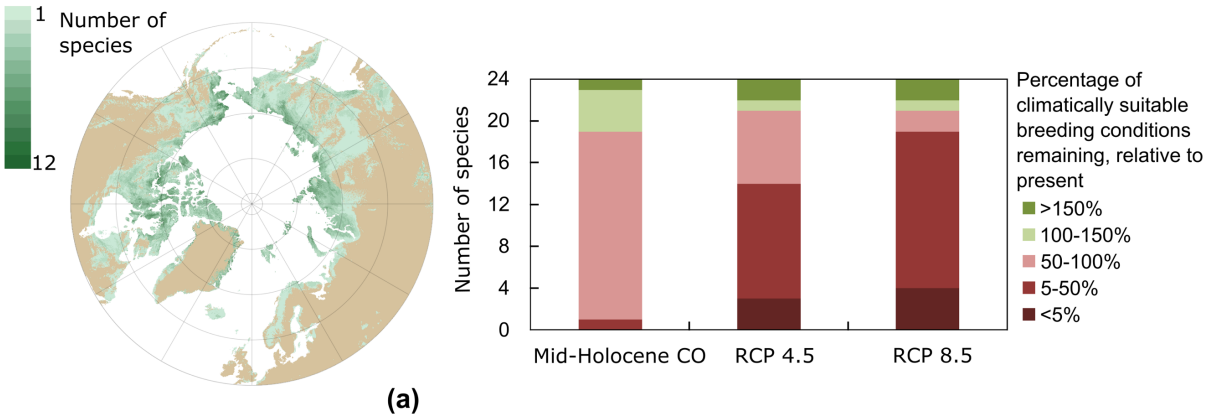
(x). Grey plover *Pluvialis squatarola*

Table S2 - Full names of CMIP5 Global Climate Models used in analysis

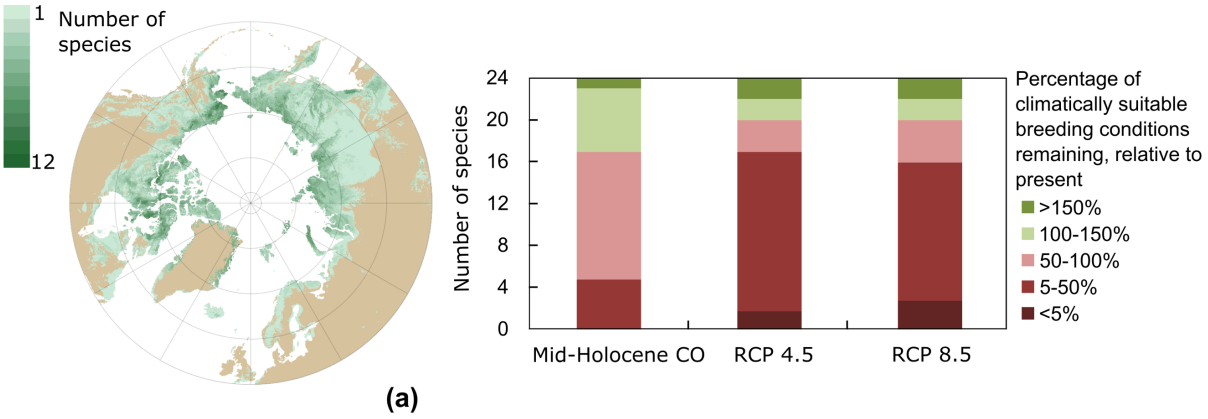
Modelling Center (or Group)	Institute ID	Model Name
Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	CSIRO-BOM	ACCESS1.0
Beijing Climate Center, China Meteorological Administration	BCC	BCC-CSM1.1
National Center for Atmospheric Research	NCAR	CCSM4
NOAA Geophysical Fluid Dynamics Laboratory	NOAA GFDL	GFDL-CM3
Met Office Hadley Centre (contributed by Instituto Nacional de Pesquisas Espaciais)	MOHC (INPE)	HadGEM2-ES
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC	MIROC-ESM



i) Predictor variables: 19 bioclimatic variables, elevation, distance to coast



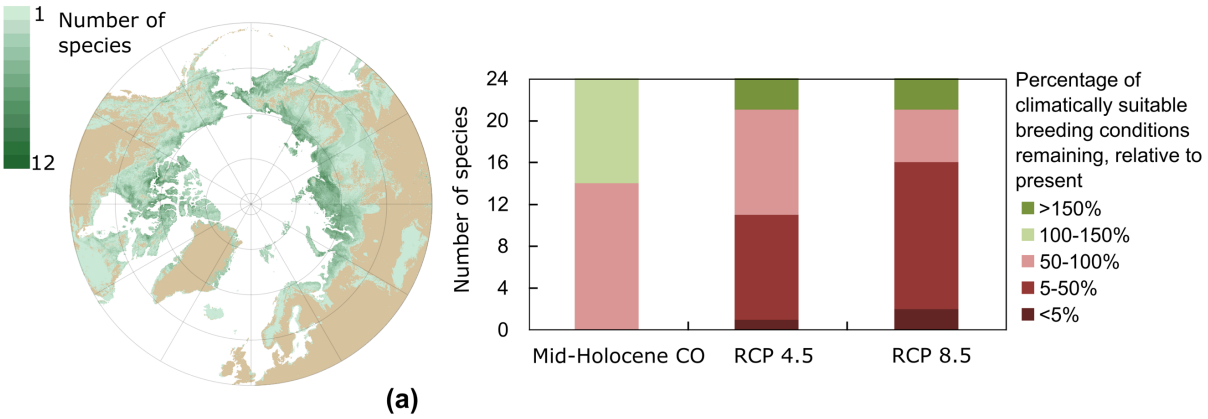
ii) Predictor variables: 19 bioclimatic variables, elevation



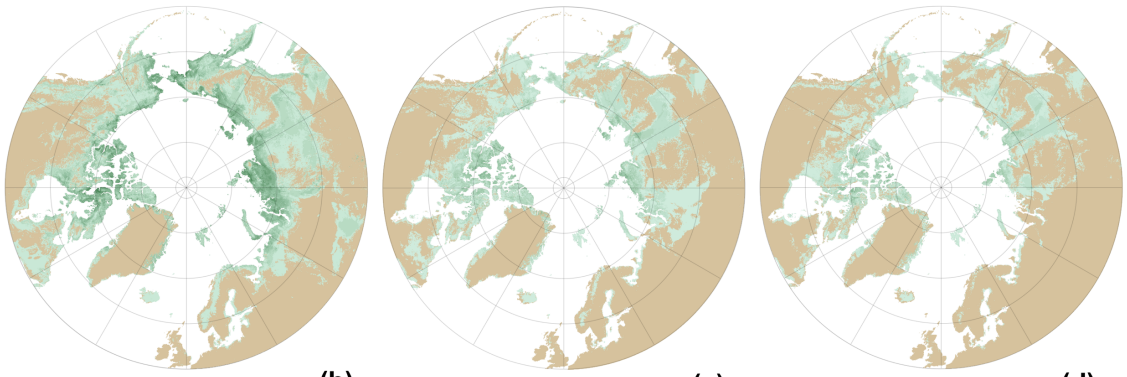
(a)

(b) (c) (d)

iii) Predictor variables: 19 bioclimatic variables



(a)



(b) (c) (d)

iii) Predictor variables: Most important and least correlated set of 5 predictor variables, individually selected for each species

Figure S2 - Model output with different predictor variables. Four iterations of predicted richness of climatically suitable breeding conditions for 24 Arctic specialist breeding shorebirds (**a**) currently, (**b**) during the Mid-Holocene climatic optimum (~6000 years ago), and in 2070 based on two climate change scenarios: (**c**) the optimistic RCP 4.5, and (**d**) the pessimistic RCP 8.5. The inset chart shows the number of species with an increase or decrease (green and red respectively, intensity of colour reflects intensity of loss or gain) in climatically suitable breeding conditions relative to the present day, for past and future scenarios.

Results are shown for four models built with different combinations of predictor variables. The first (i) was built using 19 bioclimatic variables, elevation and distance to coast. This is the model used in the paper – the figure is repeated here for ease of comparison. The second (ii) was built with distance to coast removed as a predictor variable. The third (iii) was built with elevation and distance to coast removed as predictor variables, meaning only bioclimatic variables were used to inform the model. The fourth (iv) was built with the five most important and least correlated set of variables for each species, selected from the broader set of 19 bioclimatic variables, elevation and distance to coast. Variables were selected for each species by running jack-knifed versions of the models, which test the contribution of each variable to the model fit in isolation, then the amount of information that is lost when only that variable is removed and the others kept. These runs identified the top ten most important variables for each species, and these were then reduced to five by iteratively removing the less important of each pair of highly correlated variables.

Though there is some variation between the four models (notably that with fewer predictors constraining the model, the distributions become wider, extending further into Russia and Canada), there is little difference in the broad trends. Loss of climatically suitable breeding conditions is still severe, and markedly greater in future warming scenarios than at the Mid-Holocene, loss is greatest from Beringia and mainland Russia and remaining suitable conditions concentrate in the Canadian Arctic (maps (**c**) and (**d**)). More southerly predicted distributions occur only for a few species, as indicated by the paleness of the green in the maps.

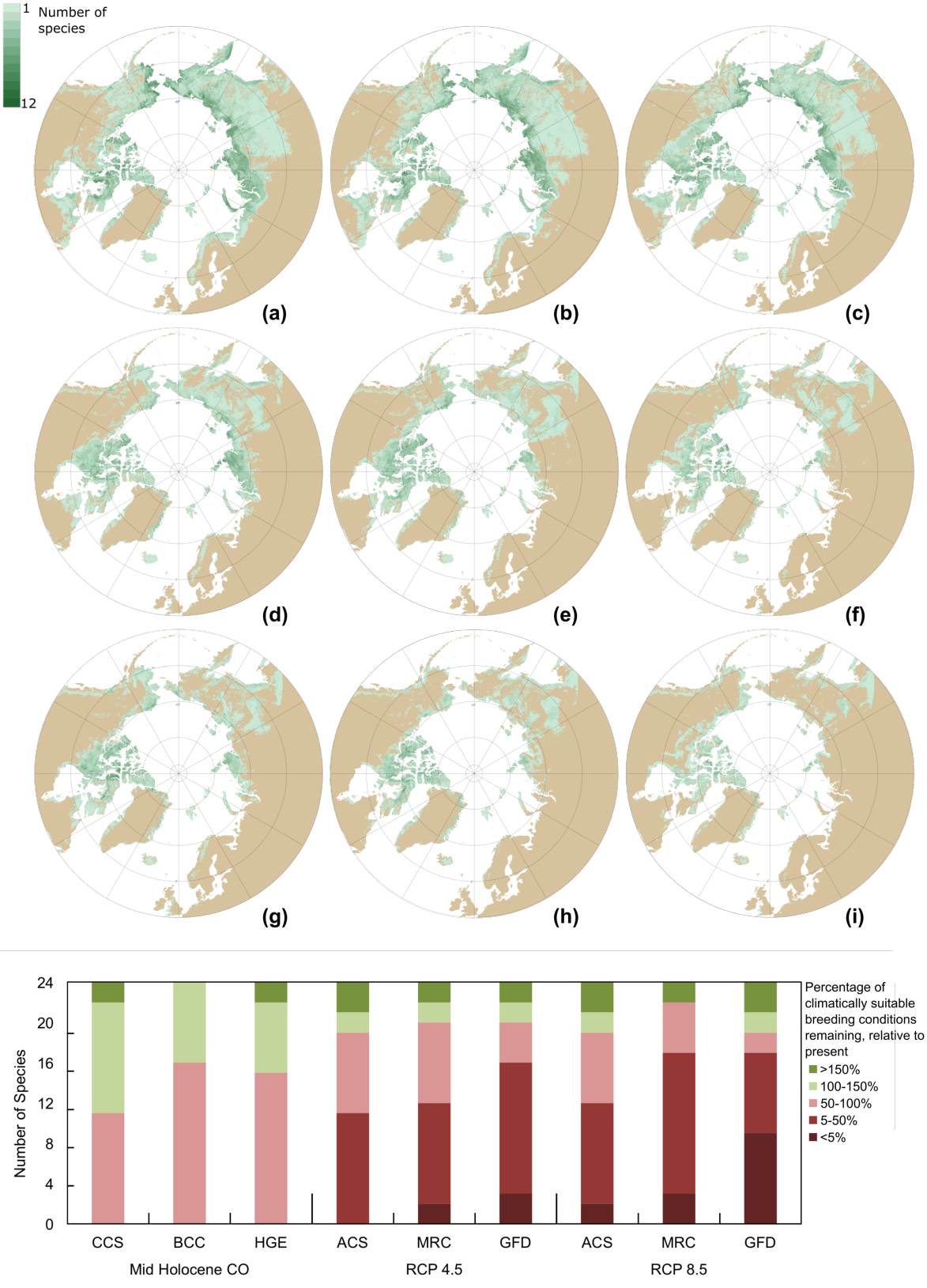


Figure S3 - Species richness maps from all Global Climate Models. Species richness maps for 24 Arctic breeding shorebird species created from modelled MaxEnt output under a number of climate scenarios and global climate models (GCMs). Maps a, b and c show richness at the Mid-Holocene climatic optimum (~6000bp) under three GCMs, CCSM4 (**a**),

BCC-CSM1.1 (**b**) and HadGEM2-ES (**c**). Maps d, e and f show richness in 2070 under RCP 4.5, under three GCMs, ACCESS1.0 (**d**), MIROC-ESM (**e**) and GFDL-CM3 (**f**). Maps g, h and i show richness in 2070 under RCP 8.5 under three GCMs, ACCESS1.0 (**g**), MIROC-ESM (**h**) and GFDL-CM3 (**i**). The inset chart shows the number of species with an increase or decrease (green and red respectively, intensity of colour reflects intensity of loss or gain) in climatically suitable breeding conditions relative to the present day for each scenario, where the acronyms are as follows: BCC = BCC-CSM1.1, CCS = CCSM4, HGE = HadGEM2-ES, ACS = ACCESS1.0, MRC = MIROC-ESM, GFD = GFDL-CM3.

Table S3 - Species climatically suitable breeding habitat data. The following tables show the proportion of increase/decrease in modelled suitable climatic breeding habitat from the current scenario to the Mid-Holocene climatic optimum (~6000bp) and 2070 under RCP 4.5 and RCP 8.5. Shown for each individual Global Climate Model, where the acronyms are as follows: BCC = BCC-CSM1.1, CCS = CCSM4, HGE = HadGEM2-ES, ACS = ACCESS1.0, MRC = MIROC-ESM, GFD = GFDL-CM3. Values range from 0.00 to 8.63, with the lowest value of 0.00 indicating that 0% of habitat remains in that scenario, and 8.63 indicating an 863% increase in habitat in that scenario.

	Mid-Holocene climatic optimum			2070 RCP 4.5			2070 RCP 8.5		
	BCC	CCS	HGE	ACS	MRC	GFD	ACS	MRC	GFD
Arenaria interpres	0.78	0.89	0.59	0.42	0.24	0.42	0.54	0.32	0.50
Calidris acuminata	1.27	1.26	1.00	0.43	0.55	0.26	0.26	0.28	0.07
Calidris alba	0.66	0.88	0.65	0.24	0.19	0.09	0.10	0.09	0.04
Calidris bairdii	1.34	1.25	1.19	0.61	0.89	1.05	0.68	0.75	1.06
Calidris canutus	0.86	1.05	0.69	0.36	0.17	0.06	0.18	0.09	0.01
Calidris ferruginea	0.63	1.09	0.50	0.26	0.02	0.00	0.03	0.00	0.00
Calidris fuscicollis	0.87	0.99	1.12	0.16	0.41	0.13	0.12	0.18	0.02
Calidris himantopus	1.21	1.92	1.22	0.37	0.13	0.02	0.07	0.03	0.00
Calidris maritima	0.58	0.69	0.61	0.83	0.68	0.43	0.70	0.54	0.35
Calidris mauri	0.77	1.20	1.54	2.04	1.95	2.55	2.63	1.86	2.29
Calidris melanotos	1.25	1.03	1.10	0.79	0.65	0.33	0.52	0.45	0.19
Calidris minuta	0.65	0.89	0.65	0.58	0.15	0.07	0.30	0.09	0.04
Calidris ptilocnemis	0.91	0.80	0.85	0.92	0.55	0.37	0.74	0.28	0.51
Calidris pusilla	0.91	0.87	1.31	1.09	1.24	0.55	1.05	0.80	0.05
Calidris pygmaea	0.57	0.81	0.80	0.69	0.63	0.87	0.28	0.36	1.69
Calidris ruficollis	0.69	0.63	0.62	0.32	0.12	0.09	0.19	0.09	0.05
Calidris subruficollis	1.13	1.52	0.79	1.46	0.35	0.62	1.21	0.29	1.16
Limnodromus scolopaceus	1.37	1.19	0.97	0.57	0.88	0.32	0.68	0.70	0.18
Limosa haemastica	1.35	1.24	1.71	3.74	5.73	8.08	5.41	7.20	8.63
Numenius tahitiensis	0.87	0.93	0.99	2.04	1.15	1.11	2.39	0.46	0.59
Phalaropus fulicarius	1.08	1.41	0.73	0.26	0.15	0.08	0.14	0.06	0.05
Pluvialis dominica	0.87	0.85	1.18	0.67	0.80	0.53	0.53	0.54	0.10
Pluvialis fulva	0.85	1.00	0.76	0.33	0.03	0.03	0.05	0.02	0.01
Pluvialis squatarola	0.83	1.16	0.69	0.40	0.30	0.17	0.31	0.21	0.10

Table S4 - Species flyway data. The following tables show the proportion of suitable climatic breeding habitat for 24 shorebird species within the polygon of each of the world's eight shorebird flyways. Proportions shown for three climate scenarios, current (Table S4.1), 2070 at RCP 4.5 (Table S4.2) and 2070 at RCP 8.5 (Table S4.3). Zeroes are shown when the species has suitable conditions occurring in that flyway in another scenario. Flyway acronyms are: ATL = Atlantic Americas, BLA = Black Sea/Mediterranean, CEN = Central Asian, EAF = East Asian/Australasian, EAS = East Atlantic, MIS = Mississippi Americas, PAC = Pacific Americas, WES = West Asia/East Africa.

Table S4.1

	ATL	BLA	CEN	EAF	EAS	MIS	PAC	WES
Arenaria interpres	0.10	___	___	0.08	0.59	0.17	___	___
Calidris acuminata	___	___	0.00	0.99	___	___	___	___
Calidris alba	0.58	0.03	0.00	0.00	0.35	0.04	___	0.00
Calidris bairdii	0.17	___	___	0.19	___	0.58	0.06	___
Calidris canutus	0.66	0.08	___	0.03	0.16	0.06	___	___
Calidris ferruginea	___	0.31	0.16	0.11	___	0.03	0.16	0.22
Calidris fuscicollis	0.29	___	___	___	___	0.71	___	___
Calidris himantopus	___	___	___	0.86	___	0.14	___	___
Calidris maritima	0.44	0.10	___	0.06	0.30	0.01	___	0.06
Calidris mauri	___	___	___	0.53	___	0.06	0.37	___
Calidris melanotos	0.18	___	0.02	0.10	___	0.66	0.02	0.01
Calidris minuta	0.06	0.35	0.25	0.03	___	___	___	0.28
Calidris ptilocnemis	___	___	___	0.40	___	___	0.60	___
Calidris pusilla	0.25	___	___	0.12	___	0.53	0.01	___
Calidris pygmaea	___	0.18	0.00	0.80	___	___	___	0.01
Calidris ruficollis	0.24	0.19	0.03	0.25	0.23	___	___	0.04
Calidris subruficollis	0.20	___	___	0.17	___	0.59	___	___
Limnodromus scolopaceus	0.23	___	0.07	0.28	___	0.28	0.12	___
Limosa haemastica	0.06	___	___	0.40	___	0.44	0.07	___
Numenius tahitiensis	___	___	___	0.99	___	0.01	___	___
Phalaropus fulicarius	0.41	___	___	0.05	0.22	0.30	0.01	___
Pluvialis dominica	0.26	___	___	0.07	___	0.63	0.04	___
Pluvialis fulva	0.02	___	___	0.63	0.02	___	0.05	0.25
Pluvialis squatarola	0.33	___	0.13	0.02	0.04	0.36	___	0.12

Table S4.2

	ATL	BLA	CEN	EAF	EAS	MIS	PAC	WES
Arenaria interpres	0.12	___	___	0.13	0.52	0.11	___	___
Calidris acuminata	___	___	0.00	1.00	___	___	___	___
Calidris alba	0.57	0.07	0.00	0.00	0.35	0.00	___	0.00
Calidris bairdii	0.15	___	___	0.21	___	0.57	0.07	___
Calidris canutus	0.66	0.00	___	0.06	0.25	0.03	___	___
Calidris ferruginea	___	0.00	0.00	0.24	___	0.09	0.64	0.00
Calidris fuscicollis	0.89	___	___	___	___	0.11	___	___
Calidris himantopus	___	___	___	1.00	___	0.00	___	___
Calidris maritima	0.50	0.11	___	0.05	0.27	0.01	___	0.05

	ATL	BLA	CEN	EAF	EAS	MIS	PAC	WES
Calidris mauri	___	___	___	0.64	___	0.07	0.24	___
Calidris melanotos	0.27	___	0.00	0.03	___	0.69	0.00	0.00
Calidris minuta	0.04	0.37	0.21	0.11	___	___	___	0.23
Calidris ptilocnemis	___	___	___	0.50	___	___	0.45	___
Calidris pusilla	0.28	___	___	0.11	___	0.52	0.01	___
Calidris pygmaea	___	0.60	0.06	0.20	___	___	___	0.11
Calidris ruficollis	0.50	0.00	0.00	0.03	0.46	___	___	0.00
Calidris subruficollis	0.08	___	___	0.13	___	0.77	___	___
Limnodromus scolopaceus	0.36	___	0.09	0.19	___	0.34	0.01	___
Limosa haemastica	0.10	___	___	0.40	___	0.37	0.07	___
Numenius tahitiensis	___	___	___	0.96	___	0.03	___	___
Phalaropus fulicarius	0.30	___	___	0.01	0.39	0.28	0.01	___
Pluvialis dominica	0.37	___	___	0.04	___	0.58	0.01	___
Pluvialis fulva	0.08	___	___	0.34	0.08	___	0.13	0.33
Pluvialis squatarola	0.40	___	0.08	0.00	0.01	0.42	___	0.08

Table S4.3

	ATL	BLA	CEN	EAF	EAS	MIS	PAC	WES
Arenaria interpres	0.30	___	___	0.03	0.45	0.16	___	___
Calidris acuminata	___	___	0.05	0.87	___	___	___	___
Calidris alba	0.39	0.04	0.07	0.10	0.21	0.10	___	0.09
Calidris bairdii	0.20	___	___	0.19	___	0.55	0.04	___
Calidris canutus	0.52	0.04	___	0.11	0.11	0.17	___	___
Calidris ferruginea	___	0.25	0.27	0.21	___	0.00	0.01	0.25
Calidris fuscicollis	0.34	___	___	___	___	0.65	___	___
Calidris himantopus	___	___	___	0.05	___	0.92	___	___
Calidris maritima	0.33	0.08	___	0.09	0.33	0.11	___	0.03
Calidris mauri	___	___	___	0.58	___	0.00	0.41	___
Calidris melanotos	0.03	___	0.10	0.45	___	0.25	0.06	0.06
Calidris minuta	0.02	0.36	0.25	0.09	___	___	___	0.26
Calidris ptilocnemis	___	___	___	0.70	___	___	0.30	___
Calidris pusilla	0.43	___	___	0.19	___	0.30	0.08	___
Calidris pygmaea	___	0.00	0.00	1.00	___	___	___	0.00
Calidris ruficollis	0.00	0.05	0.05	0.80	0.01	___	___	0.05
Calidris subruficollis	0.09	___	___	0.12	___	0.77	___	___
Limnodromus scolopaceus	0.05	___	0.04	0.66	___	0.05	0.19	___
Limosa haemastica	0.11	___	___	0.28	___	0.54	0.07	___
Numenius tahitiensis	___	___	___	0.93	___	0.07	___	___
Phalaropus fulicarius	0.25	___	___	0.19	0.04	0.40	0.07	___
Pluvialis dominica	0.19	___	___	0.16	___	0.57	0.08	___
Pluvialis fulva	0.00	___	___	0.63	0.00	___	0.00	0.37
Pluvialis squatarola	0.21	___	0.18	0.20	0.11	0.12	___	0.17

Table S5 - Species Protected Area data. The following table shows target and actual proportions of breeding habitat protected for 24 shorebird species, based on modelled suitable climatic habitat under current and future climate change scenarios. Bolded species and scenarios indicate where protection targets (see text) were not met. Shown for three climate scenarios, current, 2070 at RCP 4.5 and 2070 at RCP 8.5.

	Current		2070 RCP 4.5		2070 RCP 8.5	
	Target	Actual	Target	Actual	Target	Actual
Arenaria interpres	0.10	0.23	**0.38**	**0.20**	**0.35**	**0.25**
Calidris acuminata	0.10	0.21	0.10	0.24	0.10	0.19
Calidris alba	0.10	0.39	0.24	0.71	0.53	0.70
Calidris bairdii	0.10	0.14	0.10	0.18	0.10	0.18
Calidris canutus	0.10	0.24	0.17	0.41	0.43	0.60
Calidris ferruginea	0.10	0.24	**0.79**	**0.34**	0.96	1.00
Calidris fuscicollis	**0.10**	**0.06**	**0.67**	**0.14**	0.85	0.28
Calidris himantopus	**0.46**	**0.06**	**0.98**	**0.04**	NA	NA
Calidris maritima	0.10	0.28	0.10	0.32	0.10	0.36
Calidris mauri	0.10	0.33	0.10	0.26	0.10	0.22
Calidris melanotos	0.10	0.23	0.10	0.13	**0.10**	**0.09**
Calidris minuta	0.10	0.17	0.10	0.28	0.28	0.34
Calidris ptilocnemis	0.17	0.36	**0.55**	**0.31**	**0.66**	**0.19**
Calidris pusilla	0.10	0.14	0.10	0.13	0.10	0.11
Calidris pygmaea	**0.28**	**0.18**	**0.56**	**0.26**	**0.67**	**0.26**
Calidris ruficollis	0.10	0.13	0.38	0.48	0.58	0.92
Calidris subruficollis	0.10	0.13	0.12	0.27	0.14	0.15
Limnodromus scolopaceus	0.10	0.24	0.10	0.24	0.10	0.12
Limosa haemastica	**0.28**	**0.26**	0.10	0.19	0.10	0.22
Numenius tahitiensis	0.11	0.42	0.10	0.59	0.28	0.67
Phalaropus fulicarius	0.10	0.22	**0.35**	**0.31**	**0.66**	**0.59**
Pluvialis dominica	0.10	0.19	0.10	0.20	0.10	0.18
Pluvialis fulva	0.10	0.15	**0.30**	**0.28**	**0.63**	**0.53**
Pluvialis squatarola	0.10	0.15	0.10	0.14	**0.10**	**0.10**